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ON GREEN PRODUCTION TAXES

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Abstract

Proposals are often made to tax goods which are environmentally damaging. Many such goods are consumed both directly by households and industry at large: for example, carbon-intensive fuel, waste water or congested road space. This paper adopts a tax-reform setting to evaluate such a policy. The welfare impact is shown to depend on an input-substitution effect and an output effect on final consumption, where the latter effect can be conveniently analysed via the standard concept of the marginal welfare cost of a commodity tax. Finally, it is shown that raising a production tax is welfare enhancing if the current tax is below marginal external cost and revenues are recycled via the commodity tax with the highest marginal welfare cost.

JEL Classification: H23, D61.

Keywords: externality taxes; productive efficiency; tax reform.

[1] This paper has emerged from discussions with Bruno De Borger and Stef Proost on this topic. My thanks to them. In addition, I would like to thank Bart Capeau and seminar participants at Oxford.

1 Introduction

Environmentally damaging products are often consumed directly by households and, as intermediate inputs, by industry. A Pigovian tax, designed to correct for the market failure associated with externalities, would most naturally be levied on the gross production of such a good. For example, taxes have been proposed, or actually implemented, on:

- the carbon content of fuel: energy is both an intermediate input and consumed directly by households;
- the abstraction of water and discharge of effluent into water courses (see Cowan, 1998): water, like energy, is both an intermediate input and final consumption good;
- congested road space: roads are used by both road freight transport (an input) and by households as passenger transport;
- pesticides and nitrates (see OECD, 1995, pp.36-7, for a description of the main schemes): these are primarily, though not exclusively, used as inputs to the agricultural sector.

Raising the price of a commonly-used input, such as energy, water or road freight, is likely to increase the price of a wide range of goods. Goods produced in a manner which is relatively intensive in the use of a dirty input are likely to incur higher increases in price than less intensive goods. Central to evaluating the desirability of such a scheme is the ability to trace the impact of the tax on the pattern of final consumption by different groups in society.

Much of the existing literature on environmental taxation models environmental quality as depending on the final consumption of a dirty good rather than gross production (see, for example, Sandmo, 1975; Bovenberg and de Mooij, 1994; Schöb, 1996; or Mayeres and Proost, 2001). On the basis of the examples given, this seems overly restrictive.

The case for a green production tax builds upon the well-known findings on the desirability of intermediate input taxation in a world without externalities. For instance, Diamond and Mirrlees (1971) show that, under constant-returns to scale[2], an optimal tax system does not distort production. Newbery (1986) adopts a tax-reform approach to examine the welfare impact of introducing an input tax when only a subset of final consumption goods can be taxed. He derives a weak sufficiency condition under which such a tax is welfare improving.

Bovenberg and Goulder (1996) derive an optimal green input tax when environmental quality enters the consumer utility function in a separable manner, and has no impact on production. The optimal tax is shown to equal marginal external cost, though measured in terms of public revenues rather than private income. Calthrop, De Borger and Proost (2003) study the welfare implications of a balanced-budget tax reform for an externality-generating intermediate input, showing how desirability depends to a large extent on the magnitude of pre-existing tax distortions. Both of these papers abstract from distributional concerns. Furthermore, the latter paper adopts a specific production structure: a single good uses the environmentally damaging input. This limits the channels through which the input tax alters producer prices.

In contrast to the theoretical contribution on this topic, several authors have constructed applied general equilibrium models to compute the welfare impact of a green input tax. These models often employ a tax-reform approach: the change in welfare is computed from marginally increasing the green tax whilst using other distortionary taxes to maintain the government's budget. For example, Ballard and Medema (1993) use a 19-sector model of the US economy to simulate the impact of a pollution tax. They show that the marginal welfare cost of an additional unit of revenue raised from the pollution tax is substantially below one (and the equivalent cost of other tax instruments). However, such papers do not explicitly model the channels through which the input tax affects welfare.

This paper adopts a tax reform framework to derive the welfare impact of an increase in the tax on the gross production of a dirty good, in which the government budget is balanced by reducing a consumption tax elsewhere. It can be best seen either as extending the general approach set out in Newbery (1986) to analyse non-

[2] The result also holds if the production set is convex, as long as profits are taxed at 100 per cent.

separable externalities or as a generalisation of earlier green tax reform papers (for example, Mayeres and Proost, 2001) to include intermediate inputs. When compared to Calthrop et al. (2003), this paper adopts a general production structure and includes distributional concerns[3]. Moreover, the results of Diamond and Mirrlees (1971), Bovenberg and Goulder (1996) and Schöb (1996) appear as special cases of our central result.

2. The Model

2.1 Consumers

We assume H non-identical consumers ($h = 1,...,H$) and I consumption goods ($i = 1,...,I$). Goods $i \neq d$ are clean, while good d is a dirty good. The vector (of dimension I) of consumer h's demand is denoted by x^h, with a consumer price vector q. Consumption of leisure by consumer h is denoted by ℓ^h and is taken as the untaxed numéraire in the model. The household budget constraint is given by

$$qx^h \leq w(T - \ell^h) \quad (1)$$

for all consumers, h, where T denotes the total amount of time available and w denotes the wage rate.

Each good is subject to a specific consumption tax. However, good d, is also subject to a production tax, t. Denoting producer prices by p and a consumption tax by t, we have

$$q_i = p_i + t_i \quad \text{for} \quad i \neq d$$
$$q_i = p_i + t_i + t \quad \text{for} \quad i = d$$

The total consumption of good i is denoted by $X_i = \sum_h x_i^h$ .Consumer utility is given by a strictly quasi-concave increasing function

$$u^h(x^h, \ell^h, E) \quad (2)$$

[3] This paper is more restrictive in one sense, however: unlike Calthrop *et al.* (2003), the level of environmental quality does not enter the production function. This is discussed further below.

Maximising (2) subject to (1) gives rise to demand functions, $x^h(q,E)$ and an indirect utility function, $v^h(q,E)$.

2.2 Production

We assume a standard Leontief production structure (with substitution possibilities): ie goods are produced under constant returns to scale in a perfectly competitive market; there is no joint production, and; there is a single primary factor, taken to be labour. The unit cost function in each of the I industries is denoted by c_i, where:

$$p_i = c_i(p_1,..,p_d + t,..,p_I,w)$$

for all i. The level of environmental quality is assumed not to affect production[4]. Taxes on goods have no impact on the factor price w. Denoting the vector of gross output by Z, we note

$$Z = BX$$

where $B \equiv [I - A]^{-1}$ and A gives the input-output matrix for the economy, i.e. $[a_{ij}]$ denotes the input of good i in industry j. For future reference, we note that

$$Z_d = B'_d X = \sum_i b_{di} X_i \tag{3}$$

Under standard manipulations (see, for example, Newbery, 1986), we find:

$$\frac{\partial q_i}{\partial t} = b_{di}; \quad \frac{\partial p_i}{\partial t} = b_{di} + d_{id} \tag{4}$$

where b_{di} is the d-ith element of the matrix B and d_{id} gives the Kronecker delta ($d_{id} = 1$ if $i = d$ and 0 otherwise).

2.3 Environmental Quality

The level of environmental quality in the economy, E, depends inversely on the gross output of the dirty good d, Z_d. Thus, $E = e(Z_d)$, with $e' < 0$. It is worthwhile considering, for a moment, special cases of this formulation:

4 In general, as is well known, externalities may cause the production set to become non-convex (Starrett, 1972). It is possible to simplify matters by assuming that the production remains under constant returns to scale for any given level of the externality (see, for example, Mayeres and Proost (1997) or Calthrop *et al.* (2003). However, to simplify matters, we abstract from this issue here.

- $X_d = 0; \quad a_{di} > 0$: e.g. a tax on pesticides or on freight transport. Final consumption of the good is zero.
- $X_d = Z_d; \quad a_{di} = 0$: e.g. a tax on passenger transport (and not on freight), or a tax on pollution from household products.
- $X_d > 0; \quad a_{di} > 0$: e.g. a tax on effluent discharges, or carbon-intensive energy use or congested road use. This is the most general case, in which the good is consumed both as an intermediate input and as a final consumption good.

2.4 Government

Social welfare is assumed given by a standard Bergson-Samuelson welfare function

$$W(v^1(t, t, E), \ldots, v^H(t, t, E)) \tag{5}$$

The government's fixed revenue requirement, R, is given by:

$$R = \sum_i t_i X_i + t Z_d \tag{6}$$

3 Evaluating revenue-neutral policy reforms

We consider a revenue neutral increase in the production tax, t, where a particular consumption tax, t_k, is used to maintain the government budget constraint (6). The change in welfare can be expressed as:

$$dW = \frac{dW}{dt} dt + \frac{dW}{dt_k} dt_k \tag{7}$$

subject to:

$$dR = \frac{dR}{dt} dt + \frac{dR}{dt_k} dt_k = dR_t + dR_k = 0 \tag{8}$$

Following Ahmed and Stern (1984), we define the marginal social welfare cost of raising an additional unit of revenue via a consumption tax t_i as

$$l_i = \frac{dW/dt_i}{dR/dt_i} \quad (9)$$

The corresponding cost concept for the output tax, l_t, is defined analogously. The first useful point to note is:

Lemma 1 *The tax reform is welfare improving iff*

$$l_k > l_t$$

Proof. Simple substitution of the definition of the marginal welfare cost of raising revenue from (9) into the change in welfare given in (7), and using the constraint on revenue given in (8) reveals

$$dW = -l_t dR_t + l_k dR_t \quad (10)$$

or

$$\frac{dW}{dR_t} = l_k - l_t$$

Welfare is increased if the consumption tax used to recycle revenues has a higher marginal social welfare cost per unit revenue than the production tax.

3.1 Decomposing terms

Taking the derivative of (5) with respect to the consumption tax, t_k, allows expression (9) to be written as

$$l_k = \frac{d_k X_k + gz\,\frac{\partial Z_d}{\partial t_k}}{dR/dt_k} \quad (11)$$

in which d_i denotes the distributional characteristic of good i, and is given by

$$d_i = \sum_h \frac{b^h x_i^h}{X_i}$$

and b^h gives the social marginal utility of income i.e. using M to denote income,

$$b^h = \frac{\partial W}{\partial v^h} \frac{\partial v^h}{\partial M}$$

The direct social marginal external cost of a unit output of d is denoted by g and is given by

$$g = -\sum_h b^h \frac{\partial u^h / \partial E}{\partial v^h / \partial M} e'$$

while the feedback effect of environmental quality on final consumption is captured by the term z ,

$$z = [1 - \sum_i b_{di} \frac{\partial X_i}{\partial E} e']^{-1}$$

It is clear from expression (11) that the change in welfare can be decomposed into distinct environmental and non-environmental effects. Following Schöb (1996), we define a 'Pigouvian' cost (superscript P) and a 'Ramsey' cost (superscript R)

$$l_k = l_k^R + l_k^P$$

in which:

$$l_k^R = \frac{d_k X_k}{dR / dt_k}$$

$$l_k^P = \frac{gz \frac{\partial Z_d}{\partial t_k}}{dR / dt_k}$$

The main result of this paper arises from expressing l_t in terms of the effects on final consumption markets (via l_i) and an input-substitution effect (for a given vector of final consumption). Standard manipulations reveal (see annex):

$$l_t = \frac{\sum_i (l_i \frac{dR}{dt_i}) b_{di} + gz \left. \frac{\partial Z_d}{\partial t} \right|_X}{\sum_i \frac{dR}{dt_i} b_{di} + tz \left. \frac{\partial Z_d}{\partial t} \right|_X} \tag{12}$$

4 Main Result

Substituting terms into Lemma 1 gives rise to our central result (see annex)

$$\frac{dW}{dt} = (g - l_k t) \left(-z \left. \frac{\partial Z_d}{\partial t} \right|_X \right) + \sum_i (l_k - l_i) \frac{dR}{dt_i} b_{di} \tag{13}$$

The change in welfare from a production tax can be divided into two types of effects: firstly, as shown in the first term in expression (13), there is an *input-substitution effect*, altering the level of Z_d, for any given level of final output, X. Secondly, there is an *output effect*, which can be summarised in terms of the marginal welfare cost of consumption taxes on each market: this is captured by the second term in (13). Before examining this expression in greater detail, however, it is revealing to examine several special cases.

4.1 Special cases

Case 1: No externality - $g = 0$

In this case, expression (13) reduces to:

$$\frac{dW}{dt} = -l_k^R t \left(-z \left. \frac{\partial Z_d}{\partial t} \right|_X \right) + \sum_i (l_k^R - l_i^R) \frac{dR}{dt_i} b_{di}$$

If commodity taxes are set optimally, i.e. $l_i^R = l^R$ for all i, then the second term drops out. Furthermore, setting the production tax $t = 0$ is consistent with a welfare optimum (Diamond and Mirrlees, 1971).

Case 2: No dirty inputs

Assume $g > 0$ and $a_{di} = 0$ for all i, and thus $Z_d = X_d$. In this case, our main result simplifies to

$$\frac{dW}{dt} = \frac{dW}{dt_d} = (l_k - l_d) \frac{dR}{dt_d}$$

and hence the tax reform improves welfare iff $l_k > l_d$ (Mayeres and Proost, 2001; Schöb, 1996).

Case 3: Optimal commodity tax with externality

Assume $g > 0$ and $l_i = l$ for all i, in which case expression (13) reduces to:

$$\frac{dW}{dt} = \left(g - l\, t \right) \left(-z \left. \frac{\partial Z_d}{\partial t} \right|_X \right)$$

Hence the optimal production tax is equal to:

$$t = \frac{g}{l}$$

as shown by Bovenberg and Goulder (1996). The optimal input tax is equal to the marginal external cost measured in public revenue terms.

Case 4: Optimal Ramsey taxes only

Assume that government sets only the Ramsey component of taxes optimally, but ignores environmental concerns. Hence, $g > 0$ and $l_i^R = l^R$ for all i, which gives

$$\frac{dW}{dt} = \left(g - l_k t\right)\left(-z \left.\frac{\partial Z_d}{\partial t}\right|_X\right) + \sum_i \left(l_k^P - l_i^P\right)\frac{dR}{dt_i} b_{di}$$

As the following Lemma establishes, in this case the introduction of a production tax is welfare improving if and only if the tax reform improves environmental quality.

Lemma 2 *If the Ramsey component of commodity taxes is set optimally, it is welfare improving to introduce a production tax if and only if the tax reform improves environmental quality, i.e.*

$$\frac{dW}{dt} > 0 \Leftrightarrow \frac{dE}{dt} > 0$$

Proof. Using an analogous methodology in the derivation of (10), we can write

$$g\,\frac{dE}{dt} = g\,e'\frac{dZ_d}{dt} = e'[l_i^P - l_k^P]\frac{dR}{dt} \tag{14}$$

which is just the Pigouvian equivalent of equation (18) (in annex). Applying the same substitutions used in proceeding from equation (18) to(13), we can rewrite (14) as

$$g\,\frac{dE}{dt} = \left(g - l_k t\right)\left(-\left.\frac{\partial Z_d}{\partial t}\right|_X\right) + \sum_i \left(l_k^P - l_i^P\right)\frac{dR}{dt_i} b_{di}$$

This establishes the desired result.

Return to main result

We present a weak sufficiency condition[5] under which a production tax increases welfare:

Proposition *1* *For any given recycling instrument,* k *, if (i)* $t < \frac{g}{l_k}$*, (ii)* $l_k = Max\{l_1,..,l_I\}$ *and (iii) each tax instrument is revenue positive, ie* $dR/dt_k > 0$ *, then welfare increases when the production tax is marginally raised.*

The proof is direct[6] from equation (13). The result is surprisingly simple: a production tax is welfare improving if the current tax is below marginal external cost (correctly measured), and if revenues are recycled via the tax instrument with the highest marginal welfare cost (computed to account for distributional concerns).

5 Conclusions

Taxes on polluting products, such as energy, water or road transport, which are consumed directly and as an input to production, are commonly proposed. This paper evaluates the welfare effect of such a tax in terms of two sets of effects: firstly, an input-substitution effect, and, secondly, an output effect on final consumption markets. This welfare effect of this latter effect can be conveniently summarised using the well-known notion of the marginal welfare cost of a commodity tax. The central proposition of this paper is intuitive: raising the level of a production tax is welfare improving if the current tax is below marginal external cost, and revenues are recycled using the tax instrument with the highest marginal welfare cost.

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[5] This result can be considered as a generalised version of the Newbery (1986) result to a world with non-separable externalities.

[6] The standard concavity property of the cost function implies that the input-substitution condition is met.

References

Ahmed, E. and N.Stern, 1984, The theory of reform and Indian indirect taxes, *Journal of Public Economics*, **25**, 259-298.

Ballard, C.L. and S.G.Medema, 1993, The marginal efficiency effects of taxes and subsidies in the presence of externalities: a computational general equilibrium approach, *Journal of Public Economics*, **52**, 199-216.

Bovenberg, A.L. and R.de Mooij, 1994, Environmental Levies and Distortionary Taxation, *American Economic Review*, **94(4)**, 1085-1089.

Bovenberg, A.L and L.H.Goulder, 1996, Optimal Environmental Taxation in the Presence of Other Taxes: General-Equilibrium Analyses, *American Economic Review*, **86(4)**, 984-1000.

Calthrop, E., B.De Borger, S.Proost, 2003, *Tax reform for dirty intermediate goods: theory and an application to the taxation of freight transport*, Oxford Economics Working Paper 2003.

Cowan, S., 1998, Water pollution and abstraction and economic instruments, *Oxford Review of Economic Policy*, **14(4)**, 40-49.

Diamond, P.A. and J.A.Mirrlees, 1971, Optimal Taxation and Public Production, Part 1: Production efficiency, *American Economic Review*, **61**, 8-27.

Mayeres, I. and S.Proost, 2001, Marginal tax reform, externalities and income distribution, *Journal of Public Economics*, **79**, 343-363.

Newbery, D.M., 1986, On the desirability of input taxes, *Economics Letters*, **20**, 267-270.

OECD, 1995, *Environmental taxes in OECD Countries*, Paris.

Sandmo, A., 1975, Optimal taxation in the presence of externalities, *Swedish Journal of Economics*, **77(1)**, 86-98.

Schöb, R., 1996, Evaluating tax reforms in the presence of externalities, *Oxford Economic Papers*, **48**, 537-555.

Starrett, D., 1972, Fundamental non-convexities in the theory of externalities, *Journal of Economic Theory*, **4**, 180-199.

Annex

Deriving expression (12)

We first derive the numerator. Taking the derivative of expression (5) with respect to t, allows us to write:

$$\frac{dR}{dt}l_t = \sum_i d_i X_i b_{di} + gz\frac{\partial Z_d}{\partial t}$$
$$= \sum_i d_i X_i b_{di} + gz\left[\sum_i \frac{\partial Z_d}{\partial t_i} b_{di} + \left.\frac{\partial Z_d}{\partial t}\right|_X\right]$$

where the second line follows from expression (3). Collecting terms, and recalling the definition in (11) gives:

$$\frac{dR}{dt}l_t = \sum_i \left(l_i \frac{dR}{dt_i}\right) b_{di} + gz\left.\frac{\partial Z_d}{\partial t}\right|_X \tag{15}$$

This leaves the denominator. Using the government budget constraint, (6), we note:

$$\frac{dR}{dt_k} = X_k + \sum_i t_i \frac{dX_i}{dt_k} + t\frac{dZ_d}{dt_k}$$

which can be re-arranged to give:

$$\sum_i t_i \frac{dX_i}{dt_k} = \frac{dR}{dt_k} - X_k - t\frac{dZ_d}{dt_k} \tag{16}$$

Now take the derivative of the government budget constraint with respect to the production tax:

$$\frac{dR}{dt} = \sum_j \left(\sum_i t_i \frac{dX_i}{dt_k}\right) b_{dj} + Z_d + t\frac{dZ_d}{dt}$$

Substituting for (16), recalling (3), and noting that

$$\frac{dZ_d}{dt} = \sum_i \frac{dZ_d}{dt_i} b_{di} + \left.\frac{dZ_d}{dt}\right|_X$$

gives

$$\frac{dR}{dt} = \sum_i \frac{dR}{dt_i} b_{di} + t\left.\frac{dZ_d}{dt}\right|_X \tag{17}$$

Combining expressions (15) and (17) gives (12) as required.

Deriving expression (13)

Recall from expression (10) that

$$\frac{dW}{dt} = l_k \frac{dR}{dt} - l_t \frac{dR}{dt} \tag{18}$$

Substituting expression (17) for the first term and (15) for the second gives:

$$\frac{dW}{dt} = \left(\sum_i \frac{dR}{dt_i} b_{di} + tz \left. \frac{\partial Z_d}{\partial t} \right|_X \right) l_k - \sum_i \left(\frac{dR}{dt_i} l_i \right) b_{di} + gz \left. \frac{\partial Z_d}{\partial t} \right|_X$$

which, with simple collection of terms, gives expression (13).